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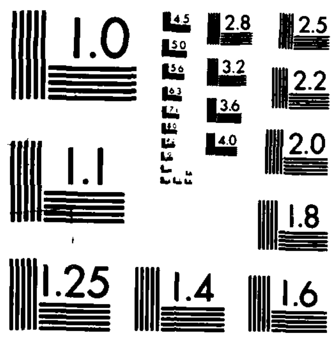
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STUDENT REPORT

REDUCTION OF ENERGY CONSUMPTION FOR AIR CONDITIONING WHILE MAINTAINING ACCEPTABLE HUMAN COMFORT

MAJOR DONALD J. MEISTER 88-1810

"insights into tomorrow"

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REPORT NUMBER 88-1810

TITLE REDUCTION OF ENERGY CONSUMPTION FOR AIR CONDITIONING WHILE MAINTAINING ACCEPTABLE HUMAN COMFORT

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Submitted to the faculty in partial fulfillment of requirements for graduation.

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This project demonstrates that energy consumption for air conditioning can be reduced while still maintaining acceptable comfort for building occupants.

The primary purpose of air conditioning is to provide a comfortable environment. However, in an era where energy cost and availability are key concerns, the goal is to provide maximum comfort at minimum cost. Information is provided on the key factors that affect comfort and a method to quantify the level of discomfort. Results of computer simulations show that the 78 degree thermostat setpoint used for air conditioning is too conservative and wastes energy. Energy consumption can be reduced by as much as 20%, depending on the climate of the location, while maintaining an acceptable thermal environment.

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PREFACE

The primary purpose of air conditioning buildings is to provide a comfortable environment in which to live and work. However, in an era in which energy cost and availability are key factors, using the least energy possible to accomplish that purpose becomes an important consideration. The goal is to provide maximum comfort at minimum cost.

There are six key variables that affect human comfort. Thermal comfort is not exclusively a function of air temperature. Thermal comfort also depends on five other, less obvious, parameters: mean radiant temperature, relative air velocity, humidity, activity level, and clothing thermal resistance. However, the combined quantitative influence of these six parameters was not known until the "Comfort Equation" established by Professor Fanger was introduced (Fanger, 1972). It is not always possible, or practical, to obtain optimal thermal comfort conditions. Therefore Professor Fanger devised an index to provide the predicted mean vote (PMV) which quantifies the level of discomfort.

Unfortunately, few people understand the complex interaction of those variables and have relied on the thermostat setpoint to determine their level of comfort. The current use of 78 degrees fahrenheit (deg-F) for the thermostat setpoint for air conditioning is too conservative and wastes energy. Higher thermostat setpoints can reduce electrical consumption and still keep building occupants comfortable.

The Air Force can save money on their utility bills in two ways: (1) reduce peak demand which determines the utility rate paid by the base and (2) reduce total consumption of electricity. The Base Commander walks a fine line between keeping his people happy and minimizing, to the extent practical, the utility bill paid by the base. This paper will provide the background and means for him to achieve both objectives.

ABOUT THE AUTHOR

Major Donald J. Meister graduated from the US Air Force Academy in 1973 with a Bachelor of Science in Civil Engineering. He was assigned to the Civil Engineering career field. In 1978, he completed a Master of Science in Facilities Management from the US Air Force Institute of Technology. Following completion of this program, he was assigned to Strategic Air Command Headquarters. While on the MAJCOM staff, he was involved in the planning of new operating bases to support the MX Missile System under the Multiple Protective Structure basing plan. One of the five major goals in the planning process was energy efficiency of the new operating bases. This experience kindled a keen interest in energy efficiency for our Air Force base facilities. In 1985, the author completed a Master of Science in Engineering Science with specialization in solar energy applications. His Master's thesis was titled, "Effects of Load Reduction Strategies on Residential Electrical Demand and Occupant Comfort." Major Meister is a Registered Professional Engineer in the State of Colorado.

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REPORT NUMBER 88-1810

AUTHOR(S) MAJOR DONALD J. MEISTER, USAF

TITLE REDUCTION OF ENERGY CONSUMPTION FOR AIR CONDITIONING WHILE MAINTAINING ACCEPTABLE HUMAN COMFORT

I. Purpose: To demonstrate that energy consumption can be reduced while still maintaining acceptable human comfort for building occupants.

II. Problem: The primary purpose of air conditioning buildings is to provide a comfortable environment in which to live and work. However, in an era when energy cost and availability are key concerns, the goal is to provide maximum comfort at minimum cost. Few people fully understand the complex interaction of the six key variables that affect human comfort. Thermal comfort is not exclusively a function of air temperature. Thermal comfort also depends on five other, less obvious, parameters: mean radiant temperature, relative air velocity, humidity, activity level, and clothing.

The current use of 78 degrees fahrenheit for the air conditioning thermostat setpoint is too conservative and wastes energy. Higher thermostat setpoints can reduce electrical

consumption and still keep building occupants satisfied. An index was developed by Professor P.O. Fanger to provide the predicted mean vote (PMV) which quantifies the level of discomfort. Pertinent Air Force manuals require compliance with American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standards.

The Air Force can save money on their utility bills in two ways: (1) reduce peak demand which determines the utility rate paid by the base and (2) reduce total consumption of electricity. The goal of the Air Force is to reduce peak load demand to reduce the rate paid and to reduce total electrical consumption.

The Base Commander walks a fine line between keeping his people happy and minimizing, to the extent practical, the utility bill paid by the base.

III. Results: The "Comfort Equation" developed by Professor Fanger was transformed into a form readily calculated on a microcomputer. Computer simulations were run with the six key variables to determine the combinations of the variables that produce acceptable thermal comfort.

The results of the computer simulations show that ambient air temperatures between 81.5 and 78.5 deg-F provide acceptable thermal comfort for at least 90% of the people at 20% to 95% relative humidity levels, respectively. The results also show that temperatures between 83 and 80 deg-F provide acceptable comfort for at least 80% of the people over the same humidity levels. Providing an acceptable environment for at least 80% of the people meets the ASHRAE requirement. Therefore, the 78 deg-F setpoint is lower than necessary to provide acceptable comfort and wastes energy.

Air Force bases were selected as representative of three climates: very hot/very dry, hot/borderline dry-humid, and hot/humid. Air conditioning cooling loads were calculated for the base line 78 deg-F setpoint as well as recommended setpoints for each location for an average July day.

While providing a thermal environment acceptable for at least 90% of the people, total daily electrical consumption was reduced from 5% to 14%. Peak demand hour consumption was reduced between 2% and 7%. For the 80% satisfaction level (the ASHRAE requirement), total consumption for the day was reduced from 12% to 21%. Peak demand was reduced from 3% to 12%.

IV. Conclusions: Acceptable human comfort can be achieved at thermostat setpoints higher than the standard 78 deg-F setpoint. The use of the 78 deg-F setpoint is too conservative and wastes energy. The Air Force can reduce energy consumption and save dollars through the use of higher setpoints. The results also show that relative humidity levels affect human comfort and should be considered in the determination of the appropriate setpoint for a given location. The results of this project are applicable to family housing units and any other areas where the activity level is light such as office/administrative areas.

V. Recommendations: An information campaign should be conducted Air Force-wide to foster a better understanding throughout all echelons of the Air Force on the subject of human comfort and the factors that affect it. The Air Force should revise its guidelines with regard to air conditioning thermostat setpoints. The Air Force should implement the basic procedure established in this project to determine the appropriate thermostat setpoint based on the environmental and personal factors for each base location and building activity level.

Chapter One

INTRODUCTION

The primary purpose of air conditioning buildings is to provide a comfortable environment in which to live and work. However, in an era in which energy cost and availability are key factors, using the least energy possible to accomplish that purpose becomes an important consideration. The designer and operators of a building who understand the effects of environmental and occupant personal variables on human comfort can optimize the building's air conditioning system for maximum comfort at minimum cost.

The current use of 78 degrees fahrenheit (deg-F) for the thermostat setpoint for air conditioning is too conservative and wastes energy. Higher thermostat setpoints can reduce electrical consumption and still keep building occupants comfortable. Also, the use of one universal setpoint for air conditioning does not account for variations in climate and their effect on human comfort.

PURPOSE

The purpose of this project is to demonstrate that energy consumption can be reduced while still maintaining acceptable human comfort. The primary thrust is to prove that acceptable human comfort can be achieved at higher thermostat setpoints based on environmental and personal factors. The secondary effort is to quantify the estimated reduction in energy consumption resulting from higher setpoints.

ORGANIZATION

Chapter One addresses the purpose of this research project and provides background information on thermal comfort and the methodology used to prove that thermal comfort can be achieved at higher thermostat setpoints than the current 78 deg-F setpoint. Chapter Two will present information on human comfort and the factors that affect it. Results of computer simulations, comparison of cooling loads associated with the various thermostat setpoints, and rough order of magnitude estimates of cooling load reductions will be presented in Chapter Three.

Chapter Four will provide conclusions drawn from the research effort and will address the applicability of the results and conclusions to the US Air Force. Recommendations will be presented in Chapter Five.

BACKGROUND INFORMATION

AFM 88-15, Air Force Design Manual - Criteria and Standards for Air Force Construction, provides design guidelines for air conditioning of USAF facilities. AFM 88-15 states, "The design, construction of equipment, installation, and testing of refrigerant systems shall conform to ... American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standards." The ASHRAE Handbook of Fundamentals makes reference to ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy", for specific combination of factors necessary for thermal comfort. ASHRAE uses the research work of Professor P.O. Fanger (Fanger, 1972) for determination of the combination of factors that provide thermal comfort. Professor Fanger was the first to quantify the combined influence of environmental and personal factors on thermal comfort. The Fanger Comfort Equation is used to predict levels of thermal comfort and remains the base line against which subsequent research on human thermal comfort is compared.

Few people fully understand the complex interaction of the six key variables that affect human comfort. Thermal comfort is not exclusively a function of air temperature. Thermal comfort also depends on five other, less obvious, parameters: mean radiant temperature, relative air velocity, humidity, activity level, and clothing thermal resistance. However, the combined quantitative influence of these six parameters was not known until the "Comfort Equation" established by Professor Fanger was introduced (Fanger, 1972). It is not always possible, or practical, to obtain optimal thermal comfort conditions. Therefore Professor Fanger devised an index to provide the predicted mean vote (PMV) which quantifies the degree of discomfort. A more detailed discussion of human comfort and the factors that affect it will be presented in Chapter Two.

There are two ways the Air Force can save money on their utility bills: (1) reduce peak demand which determines the utility rate paid by the base and (2) reduction of the total consumption of electricity. At our Air Force bases, we pay a specified electrical utility rate based on the highest single hour peak demand load and pay that rate (or 80-90% of that rate) for the next eleven months. For example, the base may pay $0.06 per kilowatt-hour (KWH) based on the peak hour electrical demand. However, if a single-hour peak demand exceeds the existing peak demand, the base may have to pay $0.075 per KWH for every KWH consumed during the next twelve months. To put this in perspective, assume the base consumed 4,000,000 KWH during the month. The difference in the utility bill due to the higher rate would be $60,000. Some bases pay electrical utility rates as high as $0.09 per KWH, and potential savings become even greater if peak load demand can be reduced. A second area for savings is reduction of total base monthly consumption.

The goal of the Air Force is to reduce peak load demand to reduce the rate paid and to reduce total electrical consumption. Therefore, it is obvious that any success in reducing peak demand load as well as total consumption can result in substantial savings in electrical utility costs due to a lower utility rate for a lesser number of kilowatt hours consumed.

Acceptance of temporary and/or minor levels of discomfort may have potential to reduce peak air conditioning loads and total electrical consumption. The average person will put personal comfort ahead of saving the USAF money on its utility bill; the Base Commander walks a fine line between keeping his people happy and minimizing, to the extent practical, the utility bill paid by the base. Therefore, any load reduction proposals, if they are to be successful, must provide acceptable levels of comfort, or only temporary and minor levels of discomfort.

METHODOLOGY

Part of the work accomplished under this project is to take Fanger's Comfort Equation and transform this complex equation into a form that can be readily calculated on a microcomputer using Turbo Pascal programming language. A listing of the computer program is provided in Appendix A. The computer model allows the designer/operator to input the six variables (four of which remain constant under most scenarios for a given facility) and get an immediate determination of the quality of the thermal environment produced by the combination of the six key factors.

This study will use a representative military family housing unit to evaluate the impact of various combinations of the six key environmental and personal factors using the ASHRAE procedure. A representative housing unit was chosen to simulate because it is a relatively small facility and puts a practical limit on this research effort. However, the results obtained by this simulation can be applied to other facilities on an Air Force base with similar activity levels. For example, an office/administrative building has the same basic activity level and metabolic rate because the majority of its occupants are involved in light/sedentary activity for a major portion of the work day.

Three representative climates (determined by outdoor dry bulb temperature and relative humidity) are selected and used to quantify the potential reduction in energy consumption resulting from revised thermostat setpoints that are appropriate for each of the selected climates. A more detailed description of the representative housing unit and climates is provided in Chapter Three.

Chapter Two

HUMAN COMFORT

The perception of comfort, temperature, and thermal acceptability are related to one's metabolic heat production, its transfer to the environment, and the resulting physiological adjustments and body temperatures (ASHRAE 55, 1981). Thermal comfort is a function of the thermal balance of the body. Specifically it involves the interaction of the environmental variables (air dry bulb temperature, mean radiant temperature, relative air velocity, and humidity) with the occupants personal variables (metabolic rate and clothing level). The benchmark work in the field of thermal comfort is the work of Professor P. O. Fanger (Fanger, 1972). Professor Fanger related thermal comfort to total thermal stress on the body.

This chapter will present general information on human comfort and the factors that affect it. Specifically, it will address the thermo-regulatory system of human beings, studies on thermal comfort, the method to predict levels of thermal comfort, and estimation of percentage of people dissatisfied with a given thermal environment.

THERMO-REGULATORY SYSTEM OF THE HUMAN BODY

A brief explanation of the thermo-regulatory system of the human being is necessary to understand what human comfort is and how it is achieved. A human being has a nearly constant internal (core) temperature of approximately 98.6 deg-F which is not influenced even by large variations in outside temperature. The core temperature can be kept constant only if there is a balance between the heat produced by the body and the heat lost to the environment (Olesen, 1982).

The body produces heat principally by metabolism (oxidation of food elements) and external work (exercising or lifting objects). Body heat loss is accomplished through evaporation (evaporation of perspiration on the skin), respiration (exhaled air is warmer than inhaled air), conduction (heat conducted through clothing), radiation (heat exchanged between the skin/clothing of the person and surrounding surfaces), and by convection (due to difference in temperature of the person's surface and room ambient air). The first condition for thermal comfort is fulfillment of the heat balance equation:

$$S = M + W + R + C + Kcl - E - RES$$

where:
- S = Heat storage
- M = Metabolic rate
- W = External work
- R = Heat exchange by radiation
- C = Heat exchange by convection
- Kcl = Heat conduction through the clothing
- E = Heat loss by evaporation
- RES = Heat exchange by respiration

Heat balance is achieved when S = 0. At a given level of activity, the mean skin temperature and perspiration loss are the only physiological parameters which influence the heat balance. For a certain person at a given activity, clothing, and environment, the heat balance can be achieved by a certain combination of mean skin temperature and perspiration loss (Olesen, 1982). Heat balance alone, however, is not sufficient to guarantee thermal comfort. There is a range of values for mean skin temperature and perspiration loss for each individual at a given activity level that produces thermal comfort.

RESEARCH STUDIES

The Institute for Environmental Research at Kansas State University, under ASHRAE contracts, has conducted extensive research on thermal comfort of clothed, sedentary subjects. Studies on over 1,600 college-age students revealed statistical correlations between comfort level, temperature, humidity, sex, and length of exposure (ASHRAE Fundamentals, 1985).

Thermal comfort is defined as the state of mind in which satisfaction is expressed with the thermal environment (Olesen, 1982). Interestingly, studies in 1961 showed that temperature criteria for thermal comfort rose steadily since 1900 (ASHRAE Fundamentals, 1985). The comfort range for dry bulb or ambient air temperature rose from 64 to 70 deg-F in 1900 to 75 to 79 deg-F in 1960. This increasing trend likely results from several factors: year-round use of lighter-weight clothing and from changing lifestyles, diets, and comfort expectations (ASHRAE Fundamentals, 1985). The history of availability and cost of energy have also conditioned many Americans to accept higher temperatures to save money on their utility bills. This same approach should be applied to Air Force personnel residing/working on-base.

Since human beings are not exactly alike, the Comfort Equation does not necessarily satisfy everyone. People do perceive a given thermal environment differently. In a study of 64 subjects, it was found that the standard deviation on the preferred ambient air temperature was 2.2 deg-F (Olesen, 1982). Other studies have shown that the preferred temperature does not differ with age groups; people cannot become adapted to prefer warmer or colder environments; men and women seem to prefer almost the same thermal environment (less than 1 deg-F difference); and use of "warm" or "cool" colors or level of noise has no effect on the preferred temperature (Olesen, 1982).

PREDICTED MEAN VOTE (PMV)

It has been known for quite a while that human thermal comfort was a function of the six environmental and personal variables. However, the combined quantitative influence of these variables was not known until the Fanger "Comfort Equation" (Fanger, 1972) was introduced.

It is not always technically possible or economically practical to provide optimal thermal comfort conditions. Therefore, it is important to be able to quantify the degree of discomfort. Based on tests conducted at Kansas State University, Professor Fanger devised an index to determine the predicted mean vote (PMV) which quantifies the comfort level. Professor Fanger developed a scale to relate how hot or cold a majority of individuals would be under a given thermal environment. The scale ranges from cold (-3), through neutral (0), to hot (+3). The scale used is:

+3	HOT
+2	WARM
+1	SLIGHTLY WARM
0	NEUTRAL
-1	SLIGHTLY COOL
-2	COOL
-3	COLD

Due to individual physiological differences, it is impossible to provide thermal comfort to 100% of the people. Professor Fanger found that the minimum percent dissatisfaction is 5% of the group (Fanger, 1972). Figure 2.1. (Fanger, 1972) shows the relationship between PMV and predicted percentage of dissatisfied (PPD).

At PMV = +0.2, about 5.8% of people are dissatisfied with the thermal conditions. At PMV = +0.5, the PPD is about 10%. Less than 20% of the people are dissatisfied at PMV = +0.8. See Table 2.1 (Fanger, 1972) for a numerical interpretation of Figure 2.1. The requirement of ASHRAE Standard 55-1981 is to provide conditions that are thermally acceptable to 80% or more of the occupants (ASHRAE, 1981). A PMV of +0.8 was chosen as the comfort control upper limit for this study.

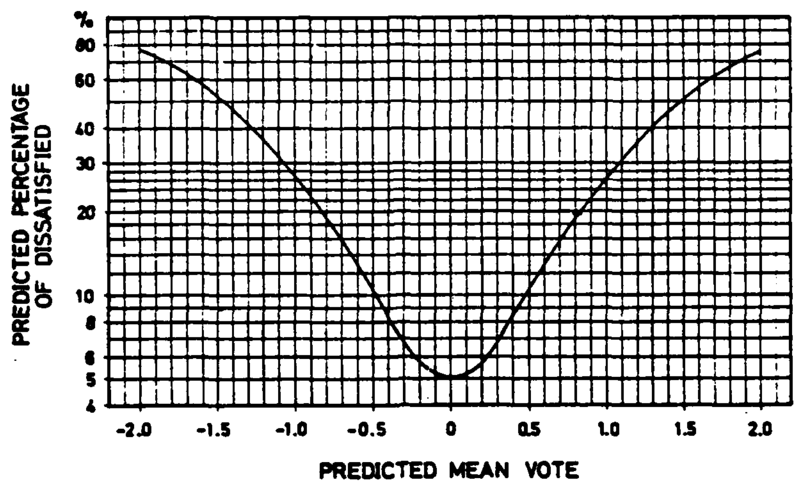

Figure 2.1. Predicted Percent Dissatisfied (PPD)

PMV	Predicted Percentage of Dissatisfied		
	Cold	Warm	Total
-1.0	26.8	-	26.8
-0.8	18.7	0.1	18.8
-0.6	12.4	0.3	12.7
-0.5	9.9	0.4	10.3
-0.4	7.7	0.6	8.3
-0.2	4.5	1.3	5.8
-0.1	3.4	1.8	5.2
0	2.5	2.5	5.0
+0.1	1.8	3.4	5.2
+0.2	1.3	4.5	5.8
+0.4	0.6	7.7	8.3
+0.5	0.4	9.8	10.2
+0.6	0.3	12.2	12.5
+0.8	0.1	18.5	18.6
+1.0	-	26.4	26.4

Table 2.1. Predicted Mean Vote vs Predicted Percent Dissatisfied (Fanger, 1972)

PMV is a function of dry bulb or ambient air temperature (Ta), mean radiant temperature (Tr), partial pressure of water vapor converted to relative humidity (RH), velocity of air (Var), resistance of clothing (CLO), and metabolic rate (MET). Sample clothing resistance values are shown in Table 2.2. Table 2.3 presents metabolic rates for various types of activity.

CLOTHING ENSEMBLE	CLO
NUDE	0
SHORTS	0.1
TROPICAL CLOTHING shorts & short sleeve shirt	0.3
SUMMER CLOTHING light-weight trousers & short sleeve shirt	0.5
LIGHT WORK CLOTHING undershirt, long sleeve shirt, & trousers	0.7
INDOOR WINTER CLOTHING undershirt, long sleeve shirt, trousers, & sweater	1.0

Table 2.2. Values of Typical Clothing Resistances (Fanger, 1972)

ACTIVITY	METABOLIC RATE
RECLINING	0.8
SEATED, QUIETLY	1.0
STANDING/SEDENTARY ACTIVITY office, dwelling	1.2
LIGHT ACTIVITY, STANDING shopping, light industry	1.6
MEDIUM ACTIVITY, STANDING domestic work, machine work	2.0
HIGH ACTIVITY	3.0

Table 2.3. Metabolic Rates For Different Activities (Fanger, 1972)

With ambient air temperature equal to mean radiant temperature (a standard assumption used in research studies), the combinations of clothing resistance, metabolic rate, relative humidity, and air velocity required to produce a PMV of 0.0 (optimum), +0.5 (90+% satisfaction), and +0.8 (80+% satisfaction) are shown in Tables 2.4-7. These tables are derived from Fanger's Comfort Equation. At low air velocities, the operative temperature (Top) is equal to the average of ambient air and mean radiant temperatures.

PMV	Top	Var	RH	CLO	MET
0.00	81.6	100	68	0.3	1.2
0.50	83.5	100	68	0.3	1.2
0.80	84.7	100	68	0.3	1.2
0.00	78.9	100	68	0.5	1.2
0.50	81.3	100	68	0.5	1.2
0.80	82.7	100	68	0.5	1.2
0.00	74.1	100	68	0.9	1.2
0.50	77.3	100	68	0.9	1.2
0.80	79.3	100	68	0.9	1.2

Table 2.4. Effect of Varying Clothing

PMV	Top	Var	RH	CLO	MET
0.00	81.0	100	68	0.5	1.0
0.50	82.9	100	68	0.5	1.0
0.80	84.1	100	68	0.5	1.0
0.00	78.9	100	68	0.5	1.2
0.50	81.3	100	68	0.5	1.2
0.80	82.7	100	68	0.5	1.2
0.00	76.9	100	68	0.5	1.4
0.50	79.7	100	68	0.5	1.4
0.80	81.4	100	68	0.5	1.4

Table 2.5. Effect of Varying Activity Rate

Table 2.4 shows the effect on Top for increases in CLO as other variables are held constant. As CLO increases, less skin is exposed and the clothing insulates the body more from the environment. Therefore, it makes sense that a lower operative temperature produces the same PMV Value as CLO increases. As clothing increases, temperature must decrease to provide the same level of comfort.

Table 2.5 shows the effect on Top for increases in MET as other variables are held constant. As MET increases, more heat is produced by the body. For a given PMV value, a lower operative temperature is necessary for the body to achieve the heat balance as MET is increased. The ambient room air temperature must be lower to allow the body to dissipate the increased heat produced by the increased MET.

PMV	Top	Var	RH	CLO	MET
0.00	79.6	100	50	0.5	1.2
0.50	82.0	100	50	0.5	1.2
0.80	83.4	100	50	0.5	1.2
0.00	78.9	100	68	0.5	1.2
0.50	81.3	100	68	0.5	1.2
0.80	82.7	100	68	0.5	1.2
0.00	78.5	100	80	0.5	1.2
0.50	80.9	100	80	0.5	1.2
0.80	82.3	100	80	0.5	1.2

Table 2.6. Effect of Varying Relative Humidity

Table 2.6 shows the effect on Top for increases in RH as other variables are held constant. As RH increases, the body loses less heat by perspiration and respiration. For a given PMV value, lower operative temperatures are necessary for the heat balance of the body to be achieved as RH is increased. Relative humidity does have an effect, but a minor one.

Table 2.7 shows the effect on Top as Var is increased while other variables are held constant. As Var increases, the body loses more heat through evaporation. Therefore, for a given PMV value, a higher operative temperature still can achieve heat balance of the body as Var is increased. Increased air velocity over the body can have a significant effect on the ambient air temperatures that provide acceptable human comfort.

PMV	Top	Var	RH	CLO	MET
0.00	75.4	20	68	0.5	1.2
0.50	78.4	20	68	0.5	1.2
0.80	80.2	20	68	0.5	1.2
0.00	78.9	100	68	0.5	1.2
0.50	81.3	100	68	0.5	1.2
0.80	82.7	100	68	0.5	1.2
0.00	79.8	160	68	0.5	1.2
0.50	82.0	160	68	0.5	1.2
0.80	83.3	160	68	0.5	1.2

Table 2.7. Effect of Varying Air Velocity

As mentioned earlier, the primary purpose of heating, ventilating and air conditioning (HVAC) systems is to provide a comfortable environment. When energy was plentiful and cheap, the economic use of HVAC systems received little attention. Systems were run until desired thermal conditions were achieved. However, in an era when energy is neither cheap nor plentiful, using the least amount of energy to achieve a comfortable environment has become a major concern. Human comfort is influenced by six key factors and yet virtually all HVAC systems are controlled only by dry bulb setpoints. Significant efficiency improvements could be achieved if HVAC systems responded to comfort levels rather than dry bulb levels (Sherman, 1985).

Chapter Three will present the results of the computer simulation of Fanger's Comfort Equation. These results show that energy savings and acceptable comfort levels can be achieved at higher thermostat setpoints.

Chapter Three

COMPUTER SIMULATION RESULTS

Results of the computer simulation of Fanger's Comfort Equation will be analyzed from two different aspects. The first aspect is the ambient temperature that provides optimum (PMV = 0) thermal comfort for the various relative humidity levels. The second aspect is the ambient temperature that provides acceptable thermal comfort for at least 90% (PMV < 0.5) and 80% (PMV < 0.8) of the people at the various relative humidity levels.

Chapter Three will specifically address the simulation results from both of these aspects, present ambient air temperature/relative humidity combinations that satisfy ASHRAE guidelines, and compare air conditioning cooling loads for the base line thermostat setpoint of 78 deg-F and the higher setpoints which provide acceptable comfort.

COMPUTER MODEL INPUT PARAMETERS

For the simulations, four of the input variables (clothing, metabolic rate, velocity of the air, and external work) are held constant. Selected values for these variables were Clo = 0.5 m2-K/W, Met = 1.2 W/m2, Var = 0.15 m/s, and W = 0. These values for these variables represent a base-case scenario with light summer clothing, minimal air movement, and an office/dwelling level of activity with no external work being performed. Only ambient air temperature and relative humidity are varied for this series of simulations. The relative humidity is varied from 20% to 95% to determine the effect of a full range (from very dry to very humid) of relative humidity levels on the thermal environment.

SIMULATION RESULTS

The results of the computer simulations are summarized in Table 3.1. The table shows the PMV for each combination of ambient air temperature and relative humidity. Positive values indicate a warm perception and negative values indicate a cool perception. A PMV value of 0 indicates the environment is perceived as neutral, neither warm nor cool. Tables 3.2 to 3.4 are subsets of Table 3.1 and specifically show the temperature/

humidity combinations that provide given, but different, levels of thermal comfort.

Relative Humidity (%)	Ambient Air Temperature (Deg-F) 76	77	78	79	80	81	82
20	(0.44)	(0.27)	(0.11)	0.06	0.23	0.40	0.57
30	(0.38)	(0.21)	(0.04)	0.14	0.31	0.48	0.65
40	(0.31)	(0.14)	0.04	0.21	0.38	0.56	0.73
50	(0.24)	(0.07)	0.11	0.28	0.46	0.64	0.81
60	(0.18)	0.00	0.18	0.36	0.54	0.72	0.90
70	(0.11)	0.07	0.25	0.43	0.61	0.79	0.98
80	(0.04)	0.14	0.32	0.50	0.69	0.87	1.06
90	0.02	0.21	0.39	0.58	0.76	0.95	1.14
95	0.06	0.24	0.43	0.61	0.80	0.99	1.18

Table 3.1. Simulation Results for PMV

SIMULATION RESULTS FOR DIFFERENT LEVELS OF COMFORT

Results of the computer simulation of Fanger's Comfort Equation that provide optimum thermal comfort are presented in Table 3.2. These results show that optimum thermal comfort is achieved by the standard Air Force setpoint for relative humidity levels up to about 50%. Remember that even at the optimum comfort level, 5% of the people will be dissatisfied with the environment. And half of these dissatisfied people will perceive the environment as cool. The ambient air temperature (Ta) is rounded to the nearest half degree.

It is important to reiterate once again that AFM 88-15 provides design guidelines for air conditioning of USAF facilities and states that the design shall conform to ASHRAE standards. ASHRAE standards establish the requirement to provide a thermal environment that is acceptable to at least 80% of the people. These results illustrate that the standard 78 deg-F setpoint provides optimum or near optimum thermal comfort for all but the highest humidity levels. In other words, the 78 deg-F setpoint provides optimum comfort for 95% of the people, clearly in excess of ASHRAE requirements. This is a strong indication that the thermostat setpoint of 78 deg-F may be too conservative and wastes energy. These results also show that relative humidity should be considered because it does affect the acceptability of the thermal environment.

Relative Humidity (%)	Ta (Deg-F)
20	78.5
30	78.5
40	78.0
50	77.5
60	77.0
70	76.5
80	76.5
90	76.0
95	76.0

Table 3.2. Temperature for Optimum Comfort

Results shown in Table 3.3 are the ambient air temperature/relative humidity combinations that provide a thermal environment acceptable to at least 90% of the people (PMV < 0.5). These results lend further support to the contention that the 78 deg-F thermostat setpoint for air conditioning is too conservative.

Relative Humidity (%)	Ta (Deg-F)
20	81.5
30	81.0
40	81.0
50	80.5
60	80.0
70	79.5
80	79.0
90	78.5
95	78.5

Table 3.3. Temperature for Acceptable Comfort for 90% of People

For every level of relative humidity, the ambient air temperature that provides an acceptable thermal environment for at least 90% of the people is in excess of 78 deg-F. Even at 95% humidity, at least 90% of the people will be satisfied with the environment at an ambient temperature of 78.5 deg-F.

Table 3.4 shows those temperature/relative humidity combinations that provide an environment acceptable to at least 80% (ASHRAE requirement) of the people. A PMV <= 0.8 is the cutoff point where more than 80% of the people will be satisfied with the thermal environment. Ambient air temperatures between 80 and 83 deg-F provide an acceptable thermal environment for at least 80% of the people for all the relative humidity levels.

Relative Humidity (%)	Ta (Deg-F)
20	83.0+
30	83.0
40	82.5
50	82.0
60	81.5
70	81.0
80	80.5
90	80.0
95	80.0

Table 3.4. Temperature for Acceptable Comfort for 80% of People

SUMMARY OF SIMULATION RESULTS

The simulation results substantiate two key assertions made in this project: (1) acceptable thermal comfort can be achieved at thermostat setpoints above the current standard setpoint of 78 deg-F and (2) relative humidity affects comfort and should be considered when determining the appropriate thermostat setpoint for a specific location with its unique climate. Table 3.4 above provides ambient air temperature/relative humidity combinations that meet the ASHRAE standards requirement. Even with 95% relative humidity, an ambient air temperature of 80 deg-F provides a thermal environment acceptable to at least 80% of the people.

It is important to remember that a PMV = 1.0 indicates a perception that the thermal environment is "slightly warm," and by no means a totally unacceptable environment. A PMV of 0.8 indicates an environment that 80% or more of the people would consider acceptable to them.

AIR CONDITIONING LOAD CALCULATION

A floor plan of the residential housing unit modeled in these computer simulations is shown in figure 3.1. Pertinent construction characteristics of the housing unit include:

1. Approximate size is 1800 square feet
2. Structure is typical wood frame construction
3. Roof is pitched with a ventilated attic
4. Floor is concrete slab on grade
5. Windows are double-glazed
6. Exterior wall insulation value is R-13
7. Ceiling insulation value is R-30

The construction details of this house are fairly standard with normal levels of insulation from an energy-conscious viewpoint, but certainly does not provide maximum energy conservation levels of insulation such as R-19+ walls and R-38+ ceilings. These nominal levels of insulation were selected due to the simple fact that USAF family housing units already exist and either already have approximately R-13 walls/R-30 ceilings or can fairly readily be modified to these levels. However, due to the expense, upgrade to R-19/R-38 is not practical.

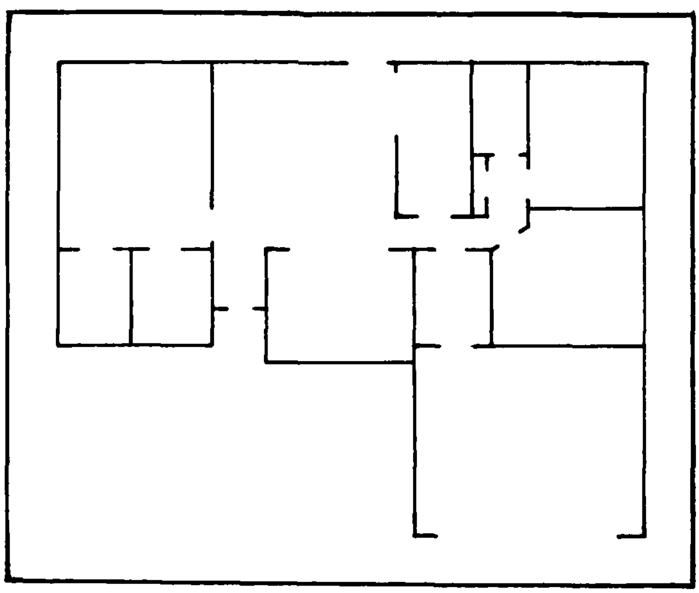

Figure 3.1. Floor Plan of Residential Housing Unit

For a given thermostat setpoint and relative humidity combination, the air conditioning cooling load can be readily calculated using the form found in Appendix B. This load calculation form is an electronic spreadsheet adaptation of the form developed by the Air Conditioning Contractors of America (McGarry, 1981). For a given relative humidity, the cooling load is proportional to the thermostat setpoint. A higher setpoint equates to less heat that must be removed from the facility. The heat to be removed is expressed in British Thermal Units (BTU's). The reduction in cooling load means that the size of the air conditioning system can be reduced and/or the air conditioning unit has to operate less to remove the reduced cooling requirement. Both of these factors will reduce the amount of electricity used to air condition a facility.

Three specific locations have been selected to illustrate approximate load reductions obtainable through the use of higher thermostat setpoints. The three locations represent three different climates with regard to temperature/humidity levels. The three locations are Luke AFB, AZ (very hot/very dry), Kelly AFB, TX (hot/borderline dry-humid), and Scott AFB, IL (hot/humid). Table 3.5 shows the temperatures for each location that provide acceptable thermal comfort for at least 90% and 80% of the people.

Location	At Least 90% Satisfied	At Least 80% Satisfied
Luke AFB, AZ	81	83
Kelly AFB, TX	80.5	82
Scott AFB, IL	80	81.5

Table 3.5. Recommended Thermostat Setpoints

The 78 deg-F setpoint is the base-case scenario against which other thermostat settings are compared. The air conditioning cooling load for each of the locations was calculated and then compared to determine the cooling load reduction achieved by the higher thermostat setpoints. The air conditioning cooling load results are analyzed from three perspectives: (1) total daily consumption, (2) peak hour demand level, and (3) air conditioner run times. The specific results for each location are presented in Tables 3.6 to 3.9. Cooling load calculations are provided for each hour of the day as well as daily total consumption. Historical mean hourly temperatures for the month of July are used for each location.

The July energy consumption reduction for Luke AFB under the 90% people satisfaction scenario is approximately 8% for the total day. Energy consumption reduction for peak hour demand is 4.3%. Due to the very hot climate at Luke AFB, the outside temperatures are always higher than the inside setpoint. This means the air conditioner will run during every hour of the day. However, the higher setpoint reduces the load for each hour and, therefore, reduces run times during the hour.

Energy consumption reduction for the 80% people satisfaction scenario is 19.2% for total daily consumption and 7.7% for peak hour demand. Air conditioner run times are reduced even further and should result in longer lives for air conditioner components.

		Thermostat Setpoint			Cooling Load Reduction at	
Hour	Temp	78	81	83	81	83
1	88	12,521	12,116	11,846	-3.23%	-5.39%
2	87	12,386	11,981	11,710	-3.27%	-5.46%
3	86	12,251	11,846	11,575	-3.31%	-5.52%
4	84	11,981	11,575	11,305	-3.39%	-5.64%
5	83	11,846	11,440	2,120	-3.43%	-82.10%
6	82	11,710	11,305	2,120	-3.46%	-81.90%
7	81	11,575	2,120	2,120	-81.68%	-81.68%
8	83	11,846	11,440	2,120	-3.43%	-82.10%
9	87	12,386	11,981	11,710	-3.27%	-5.46%
10	90	13,366	12,386	12,116	-7.33%	-9.35%
11	93	14,639	13,366	12,521	-8.70%	-14.47%
12	95	15,470	14,213	13,366	-8.13%	-13.60%
13	98	16,712	15,470	14,639	-7.43%	-12.40%
14	100	17,373	16,297	15,470	-6.19%	-10.95%
15	101	17,699	16,712	15,881	-5.58%	-10.27%
16	103	18,360	17,373	16,712	-5.38%	-8.98%
17	104	19,757	18,899	18,242	-4.34%	-7.67%
18	104	19,757	18,899	18,242	-4.34%	-7.67%
19	103	19,560	18,573	17,912	-5.05%	-8.43%
20	100	17,373	16,297	15,470	-6.19%	-10.95%
21	97	16,297	15,054	14,213	-7.63%	-12.79%
22	94	15,054	13,788	12,941	-8.41%	-14.04%
23	92	14,213	12,941	12,386	-8.95%	-12.85%
24	90	13,366	12,386	12,116	-7.33%	-9.35%
DAILY TOTAL:		357,498	328,458	288,853	-8.12%	-19.20%

Table 3.6. July Cooling Load Calculation for Luke AFB, AZ

July energy consumption reduction for Kelly AFB under the 90% people satisfaction scenario is approximately 14% for the daily total and peak hour demand is reduced by 6.9%. Temperatures at Kelly AFB are fairly high, but there are about seven hours where the outside temperature is less than the base line 78 deg-F setpoint. This means the air conditioner will run only long enough to remove the relatively small internal and infiltration load during these hours. For the higher setpoint, a couple extra hours only require removal of this small load, thereby reducing air conditioner run times even further.

		Thermostat Setpoint				Cooling Load Reduction at	
Hour	Temp	78	80	81	82	80.5	82
1	78	2,788	2,788	2,788	2,788	0.00%	0.00%
2	77	2,788	2,788	2,788	2,788	0.00%	0.00%
3	76	2,788	2,788	2,788	2,788	0.00%	0.00%
4	76	2,788	2,788	2,788	2,788	0.00%	0.00%
5	76	2,788	2,788	2,788	2,788	0.00%	0.00%
6	75	2,788	2,788	2,788	2,788	0.00%	0.00%
7	75	2,788	2,788	2,788	2,788	0.00%	0.00%
8	76	2,788	2,788	2,788	2,788	0.00%	0.00%
9	79	11,973	2,788	2,788	2,788	-76.71%	-76.71%
10	81	12,244	11,973	2,788	2,788	-39.72%	-77.23%
11	84	12,649	12,379	12,244	12,108	-2.67%	-4.28%
12	87	13,054	12,784	12,649	12,514	-2.59%	-4.14%
13	89	13,609	13,054	12,919	12,784	-4.57%	-6.06%
14	91	14,456	13,609	13,189	13,054	-7.31%	-9.70%
15	92	14,881	14,034	13,609	13,189	-7.12%	-11.37%
16	93	15,307	14,456	14,034	13,609	-6.94%	-11.09%
17	93	16,507	15,656	15,234	14,809	-6.43%	-10.29%
18	92	16,081	15,234	14,809	14,389	-6.59%	-10.52%
19	91	15,656	14,809	14,389	14,254	-6.75%	-8.96%
20	89	13,609	13,054	12,919	12,784	-4.57%	-6.06%
21	86	12,919	12,649	12,514	12,379	-2.61%	-4.18%
22	84	12,649	12,379	12,244	12,108	-2.67%	-4.28%
23	82	12,379	12,108	11,973	2,788	-2.73%	-77.48%
24	80	12,108	2,788	2,788	2,788	-76.97%	-76.97%
DAILY TOTAL:		242,385	216,058	200,606	191,437	-14.05%	-21.02%

Table 3.7. July Cooling Load Calculation for Kelly AFB, TX

Energy consumption reduction for the 80% people satisfaction scenario is 21% for total daily consumption and 10.3% for peak hour demand. Air conditioner run times are reduced even further and should contribute to longer lives for the air conditioner components.

		Thermostat Setpoint				Cooling Load Reduction at	
Hour	Temp	78	80	81	82	80	81.5
1	73	5,127	5,127	5,127	5,127	0.00%	0.00%
2	73	5,127	5,127	5,127	5,127	0.00%	0.00%
3	72	5,127	5,127	5,127	5,127	0.00%	0.00%
4	71	5,127	5,127	5,127	5,127	0.00%	0.00%
5	70	5,127	5,127	5,127	5,127	0.00%	0.00%
6	70	5,127	5,127	5,127	5,127	0.00%	0.00%
7	71	5,127	5,127	5,127	5,127	0.00%	0.00%
8	74	5,127	5,127	5,127	5,127	0.00%	0.00%
9	78	5,127	5,127	5,127	5,127	0.00%	0.00%
10	81	14,583	14,312	5,127	5,127	-1.86%	-64.84%
11	83	14,853	14,583	14,447	14,312	-1.82%	-3.19%
12	85	15,123	14,853	14,718	14,583	-1.79%	-3.12%
13	86	15,258	14,988	14,853	14,718	-1.77%	-3.10%
14	87	15,393	15,123	14,988	14,853	-1.75%	-3.07%
15	88	15,528	15,258	15,123	14,988	-1.74%	-3.04%
16	88	15,528	15,258	15,123	14,988	-1.74%	-3.04%
17	88	16,728	16,458	16,323	16,188	-1.61%	-2.82%
18	86	16,458	16,188	16,053	15,918	-1.64%	-2.87%
19	85	16,323	16,053	15,918	15,783	-1.65%	-2.89%
20	82	14,718	14,447	14,312	5,127	-1.84%	-33.96%
21	79	14,312	5,127	5,127	5,127	-64.18%	-64.18%
22	77	5,127	5,127	5,127	5,127	0.00%	0.00%
23	76	5,127	5,127	5,127	5,127	0.00%	0.00%
24	74	5,127	5,127	5,127	5,127	0.00%	0.00%
DAILY TOTAL:		246,329	234,172	218,509	213,236	-4.94%	-12.36%

Table 3.8. July Cooling Load Calculation for Scott AFB, IL

July energy consumption reduction for Scott AFB under the 90% people satisfaction scenario is approximately 4.9% for the total day and peak hour demand is reduced by 1.7%. The climate at Scott AFB is relatively hot with fairly high humidity. About half of the hours have outside temperatures that are less than the 78 deg-F base line setpoint. This reduces the potential energy consumption reduction because there are only 12 hours in the day to reduce consumption rather than a full 24 hours at Luke AFB for example.

Additionally, higher relative humidity levels create a residual internal/infiltration load twice as large as the dryer Kelly AFB climate. The higher humidity level affects the cooling load in two ways: (1) the thermostat setpoint that provides acceptable comfort is lower than at Luke or Kelly Air Force Bases and (2) the increased moisture in the air increases the cooling load. These factors further reduce the potential energy savings.

Although the air conditioner must run longer to remove the internal/infiltration load during these hours, it runs only about a third as long as it runs for the hours where the outside temperature is higher than the setpoint. For a higher setpoint, a couple extra hours only require removal of the internal/infiltration load, thereby reducing air conditioner run times.

The energy consumption reduction for the 80% people satisfaction scenario is 12.4% for total daily consumption and 3% for the peak hour demand. Air conditioner run times in each hour is reduced even further.

A summary of the cooling loads and percent reduction in the cooling load from the base-case scenario for each location is presented in Table 3.9 and 3.10. Table 3.9 provides the summary information for thermostat setpoints that provide acceptable thermal comfort for at least 90% of the people. Table 3.10 provides the same information for the setpoint that is acceptable to at least 80% of the people.

Location	Revised Setpoint (Deg-F)	Cooling Load @ 78 deg-F (BTU's)	Cooling Load @ New Setpoint (BTU's)	Percent Reduction (%)
Luke AFB, AZ	81	357,498	328,458	- 8.12 %
Kelly AFB, TX	80.5	242,385	208,332	-14.05 %
Scott AFB, IL	80	246,329	234,172	- 4.94 %

Table 3.9. Comparison of Cooling Loads for 90% Satisfaction

Location	Revised Setpoint (Deg-F)	Cooling Load @ 78 deg-F (BTU's)	Cooling Load @ New Setpoint (BTU's)	Percent Reduction (%)
Luke AFB, AZ	83	357,498	288,853	-19.20 %
Kelly AFB, TX	82	242,385	191,437	-21.02 %
Scott AFB, IL	81.5	246,329	215,872	-12.36 %

Table 3.10. Comparison of Cooling Loads for 80% Satisfaction

The 90% people satisfaction scenario can produce potential total daily energy consumption reductions of approximately 5% to 14.0%. Peak hour demand can be reduced from 1.7% to 6.9%. The 80% people satisfaction scenario can potentially reduce total daily consumption by 12.4% to 21.0% and peak hour demand has the potential to be reduced by 3.0% to 10.3%.

Both scenarios reduce air conditioner run times due to cooling load reduction. This not only saves money on utility bills, but also reduces wear and tear on the equipment and should increase the useful life of the air conditioning equipment.

AIR CONDITIONING COST ESTIMATION

Once the cooling load has been calculated for each scenario, it is relatively straightforward to calculate an approximate cost for air conditioning. The equation shown below can be used to estimate power consumption of the compressor and auxiliaries. Power consumption is calculated by taking the total cooling load, in BTU-Hour (BTUH), and dividing by the seasonal energy efficiency rating (SEER), in BTU-Hour/Watt (BTUH/W). The SEER is a measure of efficiency of air conditioning equipment. It represents the ratio of the number of BTU's of heat removed by the air conditioner for each watt of electricity used by the equipment. The higher the number, the more efficient the air conditioner is. The 1000 in the denominator converts the power consumption from watt-hours to kilowatt-hours (KWH).

$$\text{Cooling KWH} = \frac{\text{Cooling load}}{\text{SEER} \times 1000}$$

For this analysis, the value for the SEER is assumed to be nine. Many newer air conditioners have SEER values of 14 or higher. However, it must be remembered that we are dealing with existing air conditioning systems that are probably in the 7 to 10 range based on a review of manufacturer's literature from several years ago.

The air conditioning cost is determined by multiplying the electricity (KWH) used by the cost of electricity ($/KWH) to get the estimated cost in dollars. Tables 3.11 and 3.12 contain the estimated cost for the base line 78 deg-F setpoint and recommended setpoint for each location under each comfort scenario. These tables also show the estimated cost reduction achieved by using the recommended setpoints.

	78 deg-F Setpoint		Revised Setpoint		
Location	Cooling Load (KWH)	Cost ($)	Cooling Load (KWH)	Cost ($)	Cost Reduction ($)
Luke AFB, AZ	39.7	2.78	36.5	2.55	0.23
Kelly AFB, TX	26.9	1.88	23.1	1.62	0.26
Scott AFB, IL	27.4	1.92	26.0	1.82	0.10

Table 3.11. Summary of Cooling Cost Estimates (90% Satisfaction)

	78 deg-F Setpoint		Revised Setpoint		
Location	Cooling Load (KWH)	Cost ($)	Cooling Load (KWH)	Cost ($)	Cost Reduction ($)
Luke AFB, AZ	39.7	2.78	32.1	2.25	0.53
Kelly AFB, TX	26.9	1.88	21.3	1.48	0.40
Scott AFB, IL	27.4	1.92	24.0	1.68	0.24

Table 3.12. Summary of Cooling Cost Estimates (80% Satisfaction)

These results show that cost reductions ranging from 5% to 14% can be achieved if the recommended thermostat setpoints are implemented for the 90% people satisfaction scenario. Cost reductions range from 12% to 21% for the 80% people satisfaction scenario.

The estimated dollar savings seem inconsequential for each housing unit, but several key facts must be kept in mind. First, these savings are for one day only. The total monthly savings would be 30 times this amount. Additionally, total cooling season savings would be four to five times these amounts. Second, the temperatures used in calculation of the cooling load were historical averages for each hour of the day. Savings for peak cooling days would be noticeably higher and help avoid higher utility rates based on the peak hour electrical demand for the year. Third, a base may have 1,000 or more housing units so the savings are multiplied by the total number of housing units. Fourth, similar savings are achievable in any building on base where the activity is similar. Administrative/ general office-type buildings are all similar in activity level, and these facilities constitute hundreds of thousands of square feet of work space. And fifth, these savings are applicable across the entire Air Force.

Two important thoughts to emphasize in this particular section of the project are: (1) potential percent reductions in energy consumption are fairly dramatic and (2) potential dollar savings are not insignificant after consideration of the five considerations listed above.

Although these results are for the month of July only, they do provide a rough order of magnitude estimate of potential cost savings. The same procedure could be repeated for each month to get a better estimate of potential annual savings.

Chapter Four

CONCLUSIONS AND APPLICATION

In an era of tight budgetary constraints, the Air Force cannot afford to waste energy needlessly. The purpose of this project was not to save energy at the expense of building occupant comfort. To the contrary, it was to show that, based on nationally-accepted standards contained in ASHRAE standards, energy can be saved while still providing acceptable thermal comfort.

CONCLUSIONS

Acceptable human comfort can be achieved at thermostat setpoints higher than the standard 78 deg-F thermostat setpoint. Computer simulation results have substantiated that the use of a standard 78 deg-F thermostat setpoint is too conservative and wastes energy. The Air Force can reduce energy consumption and save dollars with the use of higher thermostat setpoints.

The results also show that relative humidity does have an effect on human comfort and, therefore, must be considered in determination of appropriate thermostat setpoints for a given location. Recommended thermostat setpoints will vary from one location to another due to differences in temperature and humidity. Humidity does affect human comfort, but comfort can be obtained at higher thermostat setpoints at locations with fairly high humidity levels such as Scott AFB, IL.

Higher thermostat setpoints can result in significant energy savings. Table 4.1 shows that energy savings of 4.9% to 14% can be achieved by using higher recommended thermostat setpoints while satisfying at least 90% of the people. Energy savings of 12% to 21% can be achieved while providing acceptable comfort for at least 80% of the people.

For a representative electric utility rate of $0.07/KWH, these percent reductions equate to a saving of $7.20 to $15.90 per housing unit for the month of July at these three locations. That equates to a savings of $3,600 to $7,950 if there are 500 housing units. It quickly becomes apparent that these savings can add up to rather large sums of money if you consider that savings of this general magnitude can be achieved Air Force-wide.

Location	90% People Satisfaction		80% People Satisfaction	
	Recommended Setpoint (Deg-F)	Percent Reduction (%)	Recommended Setpoint (Deg-F)	Percent Reduction (%)
Luke AFB, AZ	81	8.1%	83	19.2%
Kelly AFB, TX	80.5	14.0%	82	21.0%
Scott AFB, IL	80	4.9%	81.5	12.4%

Table 4.1. Energy Consumption Reduction Through Higher Setpoints

The reduced cooling loads also mean that air conditioner run times will be reduced. The reduced run times have two tangible benefits: (1) reduced periodic maintenance requirements and (2) increased life of air conditioning equipment components. These benefits are hard to quantify, but nonetheless are benefits attributable to higher thermostat setpoints.

APPLICABILITY

The specific model used for simulation in this research project was a residential housing unit. However, the results are applicable to any facility where the six variables are the same or similar. A good example of similar activity is an office/administrative facility where most of the activity is light activity or sedentary. In fact, an argument can be made that office/administrative facilities offer even greater potential for energy savings. This argument is based on two key facts: (1) many facilities are controlled by Energy Management and Control Systems (EMCS) where all or a large part of the facility is centrally controlled and maintaining a single setpoint for these large facilities is easy and (2) many of these facilities are occupied during the "day shift" so off-hour thermostat setpoints can be raised to achieve further energy reductions.

The results show that the recommended thermostat setpoint for acceptable thermal comfort is influenced by relative humidity. After analysis of the climate at a particular base, a recommended setpoint can be determined for any location world-wide. Therefore, the results of this research project are applicable throughout the Air Force.

Chapter Five

RECOMMENDATIONS

Based on the results of computer simulations conducted for this research project, the Air Force should revise its air conditioning guidelines and, in fact, conform to the design requirements established by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). ASHRAE is the industry standard for the commercial sector in the United States and throughout most of the world.

The Air Force Design Manual, AFM 88-15, states that design and construction shall conform to ASHRAE standards, but, in fact, they don't in the area of thermostat setpoints. AFM 88-15 states that the design should conform to ASHRAE guidelines, but also states that a setpoint of 78 deg-F should be used. It is strongly recommended that this contradiction be removed and that the requirement for conformance to ASHRAE standards be retained in AFM 88-15.

There are many misconceptions about the factors that really affect the thermal comfort of a person. Many people also have a mind set that they can only be comfortable if the thermostat is on a certain setting. People are naturally resistant to change, and any suggestion to raise thermostat setpoints will likely encounter resistance. Much of this resistance comes from a lack of understanding about the concept of thermal comfort. An Air Force-wide information campaign must be conducted to foster a better understanding throughout all echelons of the Air Force. Acceptance of higher setpoints will not happen overnight, it will take time to "overcome" the mind set that exists.

It cannot be over-emphasized that the Base Commander is not faced with an either/or decision. Energy savings and thermal comfort are not mutually exclusive. Energy consumption can be reduced and building occupants can still enjoy an environment which provides thermal comfort. It will not be easy, but the potential pay back is too great to let it die because of expected resistance.

On those facilities where EMCS is already installed, the switch to the higher setpoints is very easy and, if gradually introduced, will hardly be noticed by workers in the office/administrative facilities. With individual thermostats in most family housing units and the lack of individual unit electric meters, the switch to higher setpoints will encounter more resistance and be harder to enforce. The potential savings justify the one-time cost to install individual electric meters in the housing units so that the occupants can be held accountable for their use of electricity. The potential use of incentives for those who use less electricity than an average household should also be considered. The installation of meters and the use of incentives will involve some up front costs as well as some administrative workload, but potential savings warrant serious consideration of these measures.

The bottom line of this study is energy consumption can be reduced through the use of higher thermostat setpoints while still providing an acceptable thermal environment for building occupants. Once the facts, based on scientific research, are accepted, dollars can be saved on utility bills and used for other pressing needs.

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APPENDICES

Appendix A - Listing of Computer Program

Appendix B - Cooling Load Calculation Spreadsheet

APPENDIX A.

Listing of Computer Program

*** Program PMV - Calculates the Predicted Mean Vote ***

```
Program PMV;

var
      ta    : real; {air temp - C}
      taF   : real; {air temp - F}
      tr    : real; {mean radiant temp - C}
      V     : real; {relative air velocity - m/s}
      W     : real; {external work - W/m2}
      clo   : real; {fraction of skin area covered by clothing}
      met   : real; {activity level}
      RH    : real; {relative humidity - (fraction, not percent)}
      P1    : real;
      P2    : real;
      P3    : real;
      P4    : real;
      P5    : real;
      P6    : real;
      P7    : real;
      PMV   : real;
      ok    : boolean;


{ *** clothing ratio  -  clo *** }
function clothing_ratio (clo : real): real;
begin
  if clo < 0.5 then
    clothing_ratio := 1.0 + 0.2*clo
  else
    clothing_ratio := 1.05 + 0.1*clo;
end;


{ *** metabolic heat production  -  met *** }
function metabolic_heat_production (met : real): real; {W/m2}
begin
  metabolic_heat_production := 58.2*met;
end;
```

```
{ *** convection coefficient  -  hc *** }
function convection_coefficient (V, tc, ta : real): real;
begin
  if 2.38*sqrt(sqrt(abs(tc - ta))) > 12.1*sqrt(V) then
    convection_coefficient := 2.38*sqrt(sqrt(abs(tc - ta)))
  else
    convection_coefficient := 12.1*sqrt(V);
end;


{  *** clothing temp  -  tc *** }
function clothing_temp (V, ta, tr, M, clo, fcl, W: real): real;
var
    hc       : real;
    tc       : real;
    tc_old   : real;
    tc3      : real;
    tc4      : real;
    tr4      : real;
    a        : real;
    b        : real;
    c        : real;
    f1       : real;
    f1_prime : real;
const delta = 0.001;   {convergence criteria}
begin
  tr  := ta;
  tr4 := (tr+273)*(tr+273)*(tr+273)*(tr+273);
  a   := 35.7 - 0.028*(M-W);
  b   := 0.155*clo*3.96E-8*fcl;
  tc  := ta;  {first guess}
  repeat
    tc_old   := tc;
    hc       := convection_coefficient (V, tc, ta);
    c        := 0.155*clo*fcl*hc;
    tc3      := (tc+273)*(tc+273)*(tc+273);
    tc4      := tc3*(tc+273);
    f1       := a - b*(tc4 - tr4) - c*(tc-ta) - tc;
    f1_prime := -4.0*b*tc3 - 1.0 - c;
    tc       := tc - f1/f1_prime;
  until abs(tc_old - tc) <= delta;
  clothing_temp := tc;
end;


{ *** water vapor pressure  -  Pa *** }
function water_vapor_pressure (RH, ta: real): real;
begin
  water_vapor_pressure := RH*1.6597E11*exp(-5304/(ta+273));
end;
```

```
{  *** get input values  *** }
procedure get_input_values (var clo, met, V, W, ta, RH: real);


{ *** procedure get air temp  -  ta *** }
procedure get_air_temp (var ta, taF: real);
  begin
    write ('Air temp setpoint? ');
    readln (taF);
    writeln (Lst);
    writeln (Lst);
    ta := (taF-32)*5/9;
  end;


{ *** procedure get relative humidity  -  RH *** }
procedure get_relative_humidity (var RH: real);
  begin
    write ('Relative humidity? ');
    readln (RH);
    {ClrScr;}
  end;


{ *** print input values  *** }
procedure print_input_values (var clo, met, V, W, ta, RH: real);
  begin
    {writeln (Lst,'         Calculation of the Predicted Mean Vote (PMV)');}
    writeln (Lst);
    writeln (Lst,'         Input Variable Values:');
    writeln (Lst,'            Clo  =  ',clo:8:1,'  m2 K/W');
    writeln (Lst,'            Met  =  ',met:8:1,'  W/m2');
    writeln (Lst,'            Var  =  ',V:8:2,'  m/s');
    writeln (Lst,'            W    =  ',W:8:1,'  W/m2');
    writeln (Lst,'            ta   =  ',ta:8:1,'  deg C (',ta*9/5+32:5:1,'  deg F )');
    writeln (Lst,'            RH   =  ',RH*100:8:0,'  %');
  end;
begin
    clo  := 0.5;
    met  := 1.2;
    V    := 0.15;
    W    := 0.0;
    get_air_temp (ta, taF);
    get_relative_humidity (RH);
    print_input_values (clo, met, V, W, ta, RH);
end;
```

```
{ *** calculate PMV *** }

procedure calculate_PMV (clo, met, V, W, ta, RH, tr:real;
                         var PMV:real);
var
  fcl   : real;
  M     : real;
  Pa    : real;
  tc    : real;
  hc    : real;
begin
  fcl := clothing_ratio (clo);
  M   := metabolic_heat_production (met);
  Pa  := water_vapor_pressure (RH, ta);
  tc  := clothing_temp (V, ta, tr, M, clo, fcl, W);
  hc  := convection_coefficient (V, tc, ta);
  tr  := ta;
  writeln (Lst);
  writeln (Lst,'         Output Variable Values:');
  writeln (Lst,'            fcl  =  ',fcl:8:2);
  writeln (Lst,'            M    =  ',M:8:1,'  W/m2');
  writeln (Lst,'            Pa   =  ',Pa:8:1,'  Pa');
  writeln (Lst,'            tcl  =  ',tc:8:1,'  deg C (',tc*9/5+32:5:1,'  deg F )');
  writeln (Lst,'            tr   =  ',tr:8:1,'  deg C (',tr*9/5+32:5:1,'  deg F )');
  writeln (Lst,'            hc   =  ',hc:8:2,'  W/m2 K');

  P1  := 0.303*exp(-0.036*M) + 0.028;
  P2  := 6.93735 + 0.4539805*M -
         3.96E-8*fcl*(tc+273)*(tc+273)*(tc+273)*(tc+273);
  P3  := (3.05E-3 + 1.7E-5*M)*Pa;
  P4  := 0.0014*M*ta;
  P5  := 3.96E-8*fcl*(tr+273)*(tr+273)*(tr+273)*(tr+273);
  P6  := -fcl*hc*tc;
  P7  :=  fcl*hc*ta;
  PMV := P1*(P2 + P3 + P4 + P5 + P6 + P7);
end;


{ *** main program *** }

begin
  get_input_values (clo, met, V, W, ta, RH);
  calculate_PMV (clo, met, V, W, ta, RH, tr, PMV);
  writeln (Lst);
  writeln (Lst,'          ***    Predicted Mean Vote  =  ',PMV:4:2,'   ***');
end.
```

APPENDIX B.

Cooling Load Calculation Spreadsheet

LOCATION: Luke AFB, AZ
OUTSIDE Tdb: 104 Deg-F
INSIDE Tdb: 78 Deg-F
TEMP DELTA: 26 Deg-F

Name of Room			ENTIRE HOUSE		LIVING RM		KITCHEN		DINING RM		MSTR BEDRM		MSTR CLOSET	
Lin Ft Ext wall (Side 1:2)			124	70	20	6	8	0	16	8	20	16	10	8
Floor Area Sq. Ft.			1839		436		160		192		320		80	
Ceiling Ht, Ft			8		8		8		8		8		8	
TYPE OF EXPOSURE	Const. No.	HTM	Area	BTUH	Area	Clg	Area	Clg	Area	Clg	Area	Clg	Area	Clg
Gross Exterior Wall	12D	:::::::	992	:::::::	160	:::::::	64	:::::::	128	:::::::	160	:::::::	80	:::::::
	12D	:::::::	560	:::::::	48	:::::::	0	:::::::	64	:::::::	128	:::::::	64	:::::::
Windows and Glass Doors	North	20.0	30	600	0	0	0	0	24	480	0	0	0	0
	E/W/NE/NW	50.0	56	2800	0	0	0	0	0	0	24	1200	0	0
	S/SE/SW	30.0	96	2880	32	960	24	720	0	0	24	720	0	0
	Doors	41.0	0	0	0	0	0	0	0	0	0	0	0	0
	Skylight	148.0	4	592	0	0	0	0	0	0	0	0	0	0
Other Doors	10E	5.1	60	306	40	204	0	0	0	0	0	0	0	0
Net Exterior Wall	12D	2.1	750	1605	88	188	40	86	104	223	112	240	80	171
	12D	2.1	560	1198	48	103	0	0	64	137	128	274	64	137
Ceiling	16G	1.6	1839	2942	436	698	160	256	192	307	320	512	80	128
Floors	22A	0.0	1839	0	436	0	160	0	192	0	320	0	80	0
Infiltration		14.3	246	3513	72	1028	24	343	24	343	48	686	0	0
People & Appliances			4	2400	2	600	2	1800	0	0	0	0	0	0
Duct Gain (BTU/Hr)		0%	:::::::	0	:::::::	0	:::::::	0	:::::::	0	:::::::	0	:::::::	0
Total Sensible Gain (BTU/Hr)			:::::::	18837	:::::::	3781	:::::::	3204	:::::::	1489	:::::::	3631	:::::::	436
Air Quantities (CFM)			:::::::	691	:::::::	139	:::::::	118	:::::::	55	:::::::	133	:::::::	16

LOCATION: Luke AFB, AZ
OUTSIDE Tdb: 104 Deg-F
INSIDE Tdb: 78 Deg-F
TEMP DELTA: 26 Deg-F

Name of Room			MSTR BATH		BEDROOM 2		BEDROOM 3		LAUNDRY		BATH 2		HALLWAY	
Lin Ft Ext wall (Side 1:2)			8	4	12	14	14	14	10	0	6	0	0	0
Floor Area Sq. Ft.			80		162		189		100		60		60	
Ceiling Ht, Ft			8		8		8		8		8		8	
TYPE OF EXPOSURE	Const. No.	HTM	Area	Clg	Area	Clg	Area	Clg	Area	Clg	Area	Clg	Area	Clg
Gross Exterior Wall	12D	:::::::	64	::::::	96	::::::	112	::::::	80	::::::	48	::::::	0	::::::
	12D	:::::::	32	::::::	112	::::::	112	::::::	0	::::::	0	::::::	0	::::::
Windows and Glass Doors	North	20.0	6	120	0	0	0	0	0	0	0	0	0	0
	E/W/NE/NW	50.0	0	0	16	800	16	800	0	0	0	0	0	0
	S/SE/SW	30.0	0	0	16	480	0	0	0	0	0	0	0	0
	Doors	41.0	0	0	0	0	0	0	0	0	0	0	0	0
	Skylight	148.0	0	0	0	0	0	0	0	0	4	592	0	0
Other Doors	10E	5.1	0	0	0	0	0	0	20	102	0	0	0	0
Net Exterior Wall	12D	2.1	58	124	64	137	96	205	60	128	48	103	0	0
	12D	2.1	32	68	112	240	112	240	0	0	0	0	0	0
Ceiling	16G	1.6	80	128	162	259	189	302	100	160	60	96	60	96
Floors	22A	0.0	80	0	162	0	189	0	100	0	60	0	60	0
Infiltration		14.3	6	86	32	457	16	229	20	286	4	57	0	0
People & Appliances			0	0	0	0	0	0	0	0	0	0	0	0
Duct Gain (BTU/Hr)		0%	:::::::	0	:::::::	0	:::::::	0	:::::::	0	:::::::	0	:::::::	0
Total Sensible Gain (BTU/Hr)			:::::::	526	:::::::	2373	:::::::	1776	:::::::	676	:::::::	848	:::::::	96
Air Quantities (CFM)			:::::::	19	:::::::	87	:::::::	65	:::::::	25	:::::::	31	:::::::	4

END
DATE
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